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Sir:

Enclosed please find an application for U.S. Patent as identified below.

Inventors: Curtis L. Munson and Ralph T. Yang

Invention: **SULFUR RESISTANT ADSORBENTS**

and including: Postcard; Application including Abstract, Specification, and claims; 16 sheets of informal drawings; Two (2) facsimile copies of the two (2) executed Combined Declarations and Power of Attorneys; and Form PTO-1595 with the Assignment.

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PATENT

SULFUR RESISTANT ADSORBENTS

CROSS-REFERENCE TO RELATED APPLICATIONS

5 This application is related to co-pending United States Application Serial No. 09/177,256, filed October 22, 1998, and to United States Application Serial No. 09/179,667, filed October 27, 1998, each of which applications is incorporated herein by reference in its entirety.

10 BACKGROUND OF THE INVENTION

15 The present invention relates generally to adsorbents for selectively separating olefins from paraffins, and to adsorbents for selectively separating dienes from a mixture, particularly one containing mono-olefins. More particularly, the present invention relates to such adsorbents which are resistant to and/or tolerant of sulfur poisoning.

20 Petroleum is an extremely complex mixture and consists predominantly of hydrocarbons, as well as compounds containing nitrogen, oxygen, and sulfur. Most petroleums also contain minor amounts of nickel and vanadium. The chemical and physical properties of petroleum vary considerably because of the variations in composition.

25 The ultimate analysis (elemental composition) of petroleum tends to vary over relatively narrow limits -- carbon: 83.0 to 87.0 percent; hydrogen: 10.0 to 14.0 percent; nitrogen: 0.1 to 1.5 percent; oxygen: 0.1 to 1.5 percent; sulfur: 0.1 to 5.0 percent; metals (nickel plus 30 vanadium): 10 to 500 ppm.

35 Crude oils are seldom used as fuel because they are more valuable when refined to petroleum products. Distillation separates the crude oil into fractions equivalent in boiling range to gasoline, kerosine, gas oil, lubricating oil, and residual. Thermal or catalytic cracking is used to convert kerosine, gas oil, or residual to gasoline, lower-boiling fractions, and a residual coke. Petrochemical intermediates such as

ethylene and propylene are primarily produced by the thermal cracking of light hydrocarbon feedstocks in the presence of steam. Catalytic reforming, isomerization, alkylation, polymerization, hydrogenation, and combinations of these catalytic processes are used to upgrade the various refinery intermediates into improved gasoline stocks or distillates. The major finished products are usually blends of a number of stocks, plus additives.

10 Gasoline is a complex mixture of hydrocarbons
that distills within the range 100 to 400°F. Commercial
gasolines are blends of straight-run, cracked, reformed,
and natural gasolines. Straight-run gasoline is
recovered from crude petroleum by distillation and
contains a large proportion of normal hydrocarbons of the
15 paraffin series. Cracked gasoline is manufactured by
heating crude-petroleum distillation fractions or
residues under pressure, or by heating with or without
pressure in the presence of a catalyst. Heavier
hydrocarbons are broken into smaller molecules, some of
20 which distill in the gasoline range. Reformed gasoline
is made by passing gasoline fractions over catalysts in
such a manner that low-octane-number hydrocarbons are
molecularly rearranged to high-octane-number components.
25 Many of the catalysts use platinum and other metals
deposited on a silica and/or alumina support. Natural
gasoline is obtained from natural gas by liquefying those
constituents which boil in the gasoline range either by
compression and cooling or by absorption in oil.

30 Propylene is recovered as a by-product in the catalytic cracking of gas oils to gasoline. Catalytic cracking is a low-pressure process which normally operates at 450-600°C with a strongly acidic catalyst containing a crystalline aluminosilicate (molecular sieve). Cracking of paraffinic components proceeds by a carbonium ion mechanism which has a β -fission step similar to that found for free radicals. Lower olefins

are also recovered to a lesser extent from Fisher-Tropsch, thermal-cracking and coal-gasification units.

The presence of sulfur compounds is generally known to have deleterious effects in various petroleum refining processes. For example, in catalytic reforming, the catalyst used is often platinum supported on high-purity alumina. However, the platinum on the catalyst is seriously deactivated by sulfur compounds, and therefore the feedstock is desulfurized to less than 3 ppm by weight of sulfur before the reforming. See, for example, Tedder, J.M., A. Nechvatal and A.H. Jubb, Basic Organic Chemistry, Part 5: Industrial Products, Chapter 3.2, "Preparation of Primary Petrochemicals: Reforming," pp. 53-60 (1975).

U.S. Patent No. 6,063,723 issued to Miller also demonstrates that sulfur is known to have deleterious effects. The '723 patent discloses a sulfur tolerant zeolite catalyst for use in catalytic dehydrogenation of light paraffinic hydrocarbons. This catalyst is prepared such that it has a very specific alkali to aluminum ratio in the zeolite. Although this patent's disclosed sulfur tolerance is better than that of previously known catalysts, it is still only disclosed to be tolerant of sulfur in the range of up to 2 ppm sulfur, and more preferably up to 0.5 ppm sulfur.

Cracked gas streams include a blend of many components, including olefins, paraffins, H₂, H₂S, etc. The cracked gas streams are first subjected to caustic scrubbing in order to remove hydrogen sulfide. Then, it is necessary to separate olefins from paraffins in these streams in order to obtain a product rating. Conventional methods for such separation include multiple distillation runs, one of which removes, for example, H₂ and methane. Thereafter, the stream includes C₂'s and higher, mixed with olefins and paraffins. This stream is then distilled to separate the olefins from the paraffins. However, this distillation is very energy

intensive and difficult to accomplish because of relatively close volatilities when alkene\alkane (olefin\paraffin) separation is required. For example, ethane\ethylene separation is carried out at about -25°C and 320 psig (2.603 MPa) in a column containing over 100 trays, and propane\propylene separation is performed by an equally energy-intensive distillation at about 38°C and 260 psig (1.8 MPa). It is evident that high capital costs and high operational costs are incurred in any 10 cryogenic distillation approach.

Further, it is also very difficult to separate a diene from a mixture, particularly one containing mono-olefin. Purifying the mono-olefin, 1-butene, is particularly troublesome due to the closeness of its 15 boiling point to that of 1,3-butadiene. In order to increase the purity of 1-butene, it is necessary to separate it from other hydrocarbons. Ordinarily, fractionation alone is cost prohibitive for completely separating 1,3-butadiene to achieve the desired purity of 20 1-butene in these mixtures. Presently, butadiene is separated from olefins and paraffins primarily by distillation with selective solvents and by absorption using solutions of absorbents. Extractive distillation is relatively energy-intensive, complex and not 25 economical. There are several drawbacks, in that this puts water vapor and/or solvent vapor into the regenerated product. Further, metal salts often are 30 unstable in solution and will precipitate out of solution. Selective absorption with metal salt solution involves additional stages with recycling of streams 35 between stages to remove water vapor and/or solvent vapor from the regenerated product. This method has the disadvantage of being energy-intensive and requiring handling and recirculating of solvent streams which themselves contain contaminants or are subject to degradation. Current processes for olefin\paraffin separation have not been sufficiently selective to

economically achieve the desired result for purifying mixtures of unsaturated hydrocarbons.

Thus, it is an object of the present invention to provide adsorbents which would cost-effectively and successfully achieve separation of olefins from paraffins. It is a further object of the present invention to provide adsorbents which would cost-effectively and successfully achieve separation of dienes from mono-olefins. Still further, it is an object of the present invention to provide such adsorbents which are advantageously resistant to and/or tolerant of sulfur poisoning.

SUMMARY OF THE INVENTION

The present invention addresses and solves the above-mentioned problems and meets the enumerated objects and advantages, as well as others not enumerated, by providing novel, sulfur resistant and/or tolerant adsorbents useful in a method of separating gaseous alkene selected from the group consisting of ethylene, propylene and mixtures thereof, from a gaseous mixture including the alkene and a sulfur compound. The method comprises the steps of contacting the gaseous mixture with an adsorbent which preferentially adsorbs the alkene, at a selected temperature and pressure, thereby producing a non-adsorbed component and an alkene-rich adsorbed component; the adsorbent comprising a carrier having a surface area, the carrier having been impregnated with a silver compound by incipient wetness, thereby resulting in a monolayer of the silver compound dispersed on substantially the entire surface area, the silver compound releasably retaining the alkene; and the carrier comprising a plurality of pores having a pore size greater than the effective molecular diameter of the alkene; and changing at least one of the pressure and temperature to thereby release the alkene-rich component from the adsorbent. The adsorbent advantageously and unexpectedly substantially maintains its adsorbent

capacity and preference for the alkene in the presence of the sulfur compound.

Further novel, sulfur resistant and/or tolerant adsorbents are useful in a method for separating a diene from a mixture including the diene and a sulfur compound. The process comprises the step of contacting the mixture with an adsorbent which preferentially adsorbs the diene, at a selected temperature and pressure, thereby producing a non-adsorbed component and a diene-rich adsorbed component, wherein the adsorbent comprises an ion-exchanged zeolite selected from the group consisting of zeolite X, zeolite Y, zeolite LSX, and mixtures thereof, the zeolite having exchangeable cationic sites, and a majority of the sites having silver cation or copper cation present, and wherein the preferential adsorption occurs by π -complexation, and further wherein the adsorbent advantageously and unexpectedly substantially maintains its adsorbent capacity and preference for the diene in the presence of the sulfur compound.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the present invention will become apparent by reference to the following detailed description and drawings, in which:

Fig. 1 is a graph showing comparison of H_2S adsorption on SiO_2 and $\text{AgNO}_3/\text{SiO}_2$ at 70°C ;

Fig. 2 is a graph showing H_2S effect on olefin adsorption on $\text{AgNO}_3/\text{SiO}_2$;

Fig. 3 is a graph showing C_2H_4 cyclic adsorption on $\text{AgNO}_3/\text{SiO}_2$ at 50°C ;

Fig. 4 is a graph showing C_3H_6 cyclic adsorption on $\text{AgNO}_3/\text{SiO}_2$ at 50°C ;

Fig. 5 is a graph showing C_3H_6 cyclic adsorption on $\text{AgNO}_3/\text{SiO}_2$ at 120°C ;

Fig. 6 is a graph showing H_2S adsorption and desorption on SiO_2 at 298K ;

Fig. 7 is a graph showing H_2S adsorption and desorption on $AgNO_3/SiO_2$ at 298K;

Fig. 8 is a graph showing H_2S adsorption and desorption on $AgNO_3/SiO_2$ at 343K;

5 Fig. 9 is a graph showing the effect of H_2S poisoning on $AgNO_3/SiO_2$ capacity for C_3H_6 at 343K;

Figs. 10a and 10b are graphs showing isotherms of 1,3-butadiene and 1-butene at 120°C;

10 Fig. 11 is a graph showing Ag-Y after H_2S exposure vs. Na-Y before H_2S exposure;

Fig. 12a is an isotherm of 1,3-butadiene before and after H_2S exposure;

Fig. 12b is an isotherm of 1-butene before and after H_2S exposure;

15 Fig. 12c is a table showing calculated heat of adsorption of 1,3-butadiene and 1-butene before and after H_2S exposure;

Fig. 13 is a graph showing cumulative pore volume of Ag-Y before and after H_2S exposure;

20 Figs. 14a and 14b are fractional uptake curves of 1-butene and 1,3-butadiene before and after H_2S exposure;

25 Fig. 14c is a table showing diffusion time constants for 1,3-butadiene and 1-butene before and after H_2S exposure;

Fig. 15 is a graph showing an isotherm of benzene and 1-hexene on Ag-Y;

Fig. 16 is a graph showing H_2S isotherms on Ag-Y;

30 Fig. 17 is a graph showing isotherms of C_4H_6 and C_4H_8 on Ag-Y at 120°C;

Fig. 18 is a graph showing isotherms of 1,3-butadiene before and after H_2S exposure at 120°C;

35 Fig. 19 is a graph showing isotherms of 1-butene before and after H_2S exposure at 120°C; and

Fig. 20 is a graph showing isotherms of 1-butene and 1,3-butadiene before and after H_2S exposure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As disclosed hereinabove, it has been generally expected that adsorbents containing metal compounds would be irreversibly poisoned and rendered useless upon prolonged and/or extensive exposure to sulfur containing compounds, such as for example, hydrogen sulfide. However, in the present invention, novel adsorbents useful for cost-effective and highly successful separation of olefins from paraffins, and separation of dienes from a mixture (particularly one containing mono-olefins) have been unexpectedly and fortuitously discovered to be tolerant of and/or resistant to sulfur compounds. These inventive adsorbents have been shown to substantially maintain their selectivity and their adsorption capacity, even upon severe exposure to H₂S.

In one embodiment of the present invention, there is disclosed a novel method of separating gaseous alkene selected from the group consisting of ethylene, propylene and mixtures thereof, from a gaseous mixture including the alkene and a sulfur compound. The method comprises the step of contacting the gaseous mixture with an adsorbent which preferentially adsorbs the alkene, at a selected temperature and pressure, thereby producing a non-adsorbed component and an alkene-rich adsorbed component.

The adsorbent comprises a carrier having a surface area, the carrier having been impregnated with a silver compound by incipient wetness, thereby resulting in a monolayer of the silver compound dispersed on substantially the entire surface area. The silver compound releasably retains the alkene; and the carrier comprises a plurality of pores having a pore size greater than the effective molecular diameter of the alkene.

It is to be understood that any suitable carrier may be used. However, in a preferred embodiment, the carrier has a BET surface area greater than about 50 square meters per gram and up to about 2,000 square

5 meters per gram, and comprises a plurality of pores having a pore size greater than about 3 angstroms and up to about 10 microns. In a more preferred embodiment, the carrier is a high surface area support selected from the group consisting of refractory inorganic oxide, molecular sieve, activated carbon, and mixtures thereof. Still more preferred, the carrier is a refractory inorganic oxide selected from the group consisting of pillared clay, alumina and silica.

10 It is also to be understood that any suitable silver compound may be used. However, in a preferred embodiment, the silver compound is a silver (I) halide. In a more preferred embodiment, the silver compound is a silver salt, and the salt is selected from the group consisting of acetate, benzoate, bromate, chlorate, perchlorate, chlorite, citrate, fluoride, nitrate, nitrite, sulfate, and mixtures thereof.

15 In one exemplary embodiment of this embodiment of the present invention, the silver compound is silver nitrate (AgNO_3) and the carrier is silica (SiO_2).

20 The method of the present invention may further comprise the step of changing at least one of the pressure and temperature to thereby release the alkene-rich component from the adsorbent. It is to be understood that the pressures and temperatures used may be within a suitable range. However, in the preferred embodiment, the selected pressure of preferential adsorption is a first pressure, and the pressure of release is a second pressure less than the first pressure. In a more preferred embodiment, the first pressure is in a range of about 1 atmosphere to about 35 atmospheres, and the second pressure is in a range of about 0.01 atm to about 5 atm.

25 In the preferred embodiment, the selected temperature of preferential adsorption is a first temperature, and the temperature of release is a second temperature greater than the first temperature. In a

more preferred embodiment, the first temperature is in a range of about 0°C to about 50°C, and the second temperature is in a range of about 70°C to about 200°C.

Without being bound to any theory, it is believed that the retaining of the alkene is accomplished by formation of π -complexation bonds between the silver compound and the alkene. Separation by π -complexation is a subgroup of chemical complexation where the mixture is contacted with a second phase, which contains a complexing agent. The advantage of chemical complexation is that the bonds formed are stronger than those by van der Waals forces alone, so it is possible to achieve high selectivity and high capacity for the component to be bound. At the same time, the bonds are still weak enough to be broken by using simple engineering operations such as raising the temperature or decreasing the pressure.

The π -complexation generally pertains to the main group (or d-block) transition metals, that is, from Sc to Cu, Y to Ag, and La to Au in the periodic table. These metals or their ions can form the normal σ bond to carbon and, in addition, the unique characteristics of the d orbitals in these metals or ions can form bonds with the unsaturated hydrocarbons (olefins) in a nonclassic manner. This type of bonding is broadly referred to as π -complexation, and has been considered for gaseous hydrocarbon separation and purification using cumbersome liquid solutions.

As demonstrated further hereinbelow, this novel adsorbent fortuitously and unexpectedly substantially maintains its adsorbent capacity and preference for the alkene in the presence of the sulfur compound. This is highly desirable, as this sulfur tolerant and/or resistant adsorbent (as well as the other novel adsorbents described hereinbelow) obviates step(s) conventionally necessary to desulfurize the cracked gas stream(s).

In a further embodiment, a novel method is disclosed for separating a diene from a mixture including the diene and a sulfur compound. The process comprises the step of contacting the mixture with an adsorbent which preferentially adsorbs the diene, at a selected temperature and pressure, thereby producing a non-adsorbed component and a diene-rich adsorbed component. The adsorbent comprises an ion-exchanged zeolite selected from the group consisting of zeolite X, zeolite Y, zeolite LSX, and mixtures thereof, the zeolite having exchangeable cationic sites, and a majority of the sites have silver cation or copper cation present. In the more preferred embodiment, the majority of the cationic sites of the ion-exchanged zeolite contain silver cation. In an even more preferred embodiment, essentially all cationic sites of the ion-exchanged zeolite contain the silver cation.

Without being bound to any theory, it is believed that the preferential adsorption occurs by π -complexation.

In a preferred embodiment, the diene is selected from the group consisting of butadiene, hexadiene, octadiene and mixtures thereof. In an exemplary embodiment, the diene is 1,3-butadiene, and the mixture includes 1,3-butadiene and at least one other C₄ unsaturated compound. In a further exemplary embodiment, the mixture comprises at least one mono-olefin having as many carbon atoms as the diene, the diene is selected from the group consisting of butadiene, hexadiene, octadiene, and mixtures thereof; and the mono-olefin is selected from the group consisting of butene, hexene, octene, and mixtures thereof. In an exemplary example, the mono-olefin is butene and the diene is butadiene. The mono-olefin may be in a gaseous state and saturated with the diene.

The method may further comprise the step of changing at least one of the pressure and temperature to

thereby release the diene-rich component from the adsorbent. In a preferred embodiment, the selected pressure of preferential adsorption is a first pressure, and the pressure of release is a second pressure less than the first pressure. In a more preferred embodiment, the first pressure is in a range of about 1 atmosphere to about 35 atmospheres, and the second pressure is in a range of about 0.01 atmosphere to about 5 atmospheres. Further, the selected temperature of preferential adsorption is a first temperature, and the temperature of release is a second temperature greater than the first temperature. In a preferred embodiment, the first temperature is in a range of about 0°C to about 150°C, and the second temperature is in a range of about 70°C to about 250°C.

This adsorbent also fortuitously and unexpectedly substantially maintains its adsorbent capacity and preference for the diene in the presence of the sulfur compound.

In an alternate embodiment, a method is disclosed for separating a diene from a mixture including the diene and a sulfur compound. In an exemplary embodiment, the diene is selected from the group consisting of butadiene, hexadiene, octadiene, and mixtures thereof. The process comprises the step of contacting the mixture with an adsorbent which preferentially adsorbs the diene at a first temperature, thereby producing a non-adsorbed component and a diene-rich adsorbed component. The adsorbent comprises zeolite A having exchangeable cationic sites, a plurality of the zeolite A sites having an alkali metal cation or an alkaline earth metal cation present.

The method may further comprise the step of releasing the diene-rich adsorbed component from the adsorbent by elevating the temperature to a second temperature which ranges between about 70°C and about 120°C.

In a preferred embodiment, a selected pressure of preferential adsorption is a first pressure, and a pressure of release is a second pressure less than the first pressure, wherein the first pressure is in a range of about 1 atmosphere to about 35 atmospheres, and the second pressure is in a range of about 0.01 atmosphere to about 5 atmospheres.

This adsorbent also fortuitously and unexpectedly substantially maintains its adsorbent capacity and preference for the diene in the presence of the sulfur compound.

As demonstrated below, the sulfur compound is generally hydrogen sulfide. The novel adsorbents were exposed to very severe amounts, for example the hydrogen sulfide was present in amounts up to about 66 mole%. In sharp contrast, a conventional cracked gas stream before any desulfurizing distillation steps contains hydrogen sulfide present in amounts of about 0.01 mole%. As such, the data presented hereinbelow indicate that the novel adsorbents of the present invention would be quite robust, ie. very tolerant and/or resistant to H₂S under normal operating conditions.

To further illustrate the present invention, the following examples are given. It is to be understood that these examples are provided for illustrative purposes and are not to be construed as limiting the scope of the present invention.

EXAMPLES

Effect of sulfur compounds on olefin selective sorbents

In order to study the effect of sulfur compounds on the AgNO₃/SiO₂ sorbent, Hydrogen Sulfide (H₂S) was used as a model compound. Several isotherms of H₂S were measured at 70°C over AgNO₃/SiO₂ and SiO₂ sorbents and are shown in Figure 1. H₂S adsorption on AgNO₃/SiO₂ was mostly reversible with only about 0.04 mmol/g of H₂S left on the surface. The effect of H₂S on olefin adsorption on AgNO₃/SiO₂ can be observed in Figure

2. After the sorbent was exposed to 1 atm of H_2S at 70°C, C_3H_6 capacity at 1 atm and 70°C was reduced from 1.6 to 1.5 mmol/g. This constituted a 6% reduction in C_3H_6 capacity. While it seems that the sorbent is affected negatively by the presence of H_2S , its effects were not as harmful as expected. Therefore, minimal or accidental exposure to sulfur compounds would not result in the total loss of the adsorption bed.

Silica gel is a very good sorbent for both olefins and paraffins, but it does not have selectivity (about 1.1) for one as opposed to the other. In the presence of H₂S, it can be seen that the inventive sorbent(s) have about the same selectivity as they had before exposure to H₂S. One can conclude from this that the hydrocarbons are fortuitously adsorbing even on sulfur covered surfaces.

In the following cycling studies many ethylene and propylene adsorption cycles were run on $\text{AgNO}_3/\text{SiO}_2$. There was virtually no capacity loss below 50°C.

Cycling Studies

These are simply many adsorption experiments repeated continuously using the same adsorbent. The data correspond to 80 cycles of 20 minutes each. A straight, horizontal line on the plot means that the equilibrium loading is the same for every cycle. This suggests that the Ag^+ remains fully active on the adsorbent throughout the service life. The 50°C graphs (Figures 3 and 4) for C_2H_4 and C_3H_6 are not exactly horizontal, although they do show a consistent loading range throughout many cycles.

The 120°C data (Figure 5) for C₃H₆ however, shows that loading begins to decrease sharply initially, and then to a new plateau. The loss of capacity likely suggests that some of the Ag⁺ sites are somehow losing activity. High temperatures usually accelerate the rate of degradation for all adsorbents in general.

H₂S Adsorption/Desorption on AgNO₃/SiO₂

C₃H₆ has been shown to be readSORBED at 70°C onto a AgNO₃/SiO₂ adsorbent that was previously exposed to 1 atm of H₂S. As shown in the earlier graphs, it appears that a substantial portion of the H₂S desORBS upon lowering the pressure. See Figures 6-8. The "poisoned" adsorbent thus refers to adsorbent containing residual H₂S that is adsorbed irreversibly. From the C₃H₆ data (Figure 9), we see that the capacity has diminished only slightly.

Sorbent for purification of 1-Hexene by removal of benzene

See Figure 15.

Effects of H₂S on AgY zeolite for 1,3-Butadiene/1-Butene Adsorption

Some H₂S is adsorbed on Ag-Y irreversibly. However, purification capability of Ag-Y was maintained by shifting the adsorption of both adsorbates to higher pressure. See Figures 10-14.

Purification of butene by removal of trace amounts of butadiene was successfully achieved at Chevron by using Ag ion-exchanged zeolite (Ag-Y). In an actual purification process, certain amounts of H₂S and H₂ may be present in the process stream. In this report, the effect of H₂S exposure on butadiene/butene adsorption will be examined.

Experimental

Ag-Y (Si/Al=2.43) was prepared by the ion exchange of Na-Y (Si/Al=2.43, Strem Chemical) in excess amounts of Ag cations. First the gas phase adsorption isotherms of H₂S were measured at 25 - 180°C using a gravimetric method (SHIMADZU TGA-50) in order to understand the reversibility of H₂S adsorption on Ag-Y. Then, isotherms of 1,3-butadiene and 1-butene on Ag-Y were examined before and after H₂S exposure. The sorbent was subjected to H₂S exposure at 0.66 atm for 10 minutes at either room temperature or 120°C, which is extremely

severe compared to the actual level of H₂S present in the process stream, so that the effect on the sorbent after long time usage can be understood.

Results and Discussion

5 Adsorption and desorption isotherms of H₂S on Ag-Y at 25°C, 70°C and 120°C are shown in Figure 16. It was found that H₂S was irreversibly adsorbed on Ag-Y at lower pressure ranges less than 0.2 atm. Also, a fairly large amount of H₂S was adsorbed on Ag-Y even at a low 10 pressure of 7x10⁻⁴ atm. At 180°C (not shown here), the weight of Ag-Y in the TGA-50 increased continuously in the presence of H₂S. These results indicate a reaction between Ag-Y and H₂S occurred at 180°C and even at lower 15 temperatures such as 25 - 120°C. One possible reaction is the formation of Ag₂S. Actually, the color of Ag-Y changed from white to dark brown, which is the color of Ag₂S. Analytical investigation such as XPS (X-ray Photoelectron Spectroscopy) would be helpful to understand the reaction products.

20 Adsorption isotherms of 1,3-butadiene and 1-butene are plotted in Figure 17, compared with isotherms of the adsorbates for the novel adsorbents having not been exposed to H₂S (labelled "Joel et al."). Isotherms of both adsorbates in the present invention have a lower 25 threshold pressure than those labelled "Joel et al." The threshold pressure is the value where the steep rise in the isotherm occurs. At present, the reason for this difference is not clear except the sample preparation conditions were slightly different. However, based on 30 the results in Fig. 17, the sorbent in this work is also useful for purification of butene by removal of butadiene and was used for further studies on the H₂S effect.

35 The effect of H₂S on adsorption isotherms of butadiene and butene are examined in Figures 18 and 19, respectively. Irreversible H₂S adsorption amounts after H₂S exposure are indicated in the figures. In both cases, adsorption amounts at the same partial pressure

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were decreased. And the partial pressures of adsorbates for the same adsorption amounts were shifted to higher pressures by H₂S exposure. However, it was clearly demonstrated that Ag-Y sorbent maintained its 5 purification capability even after this severe H₂S exposure test as shown in Figure 20, which compares isotherms of Ag-Y containing 2.0-2.3 mmol/g of irreversibly adsorbed H₂S.

10 Although some H₂S appeared to be irreversibly adsorbed on Ag-Y, purification capability of Ag-Y was maintained by shifting the adsorption of both adsorbates to higher pressures.

15 In conclusion, as stated above, H₂S is always present to some extent in cracked gas streams. It is typically removed with conventional technology prior to the olefin-paraffin separation step. In the case of Ag⁺-based systems (eg. the classical, aqueous AgNO₃, adsorption systems), the presence of H₂S leads to loss of silver ions through the formation of silver sulfide, 20 Ag₂S. The reaction between H₂S and Ag⁺ ions in water is known to occur very readily. The Ag₂S formed is a finely-divided precipitate that is highly insoluble in water. The room temperature solubility of AgNO₃ in water is 216 g/L, while that of Ag₂S is 1.4 X 10⁻⁴ g/L. For 25 solid adsorbents containing monodispersed or ion-exchanged Ag⁺, one would expect a similar sulfide-forming reaction to occur with H₂S. That is, some or all of the Ag⁺ will likely "come off" of the adsorbent as Ag₂S particles. The effectiveness of the adsorbent for 30 olefins should therefore be greatly reduced.

35 The present inventive findings are unexpected and remarkable in this regard. From the collected data, there is evidence that some H₂S adsorbs irreversibly onto AgY and AgNO₃/SiO₂. However, it appears that the adsorbents still have sufficient capacity and selectivity for olefins over paraffins. Without being bound to any theory, it is believed that the reason for this may be

that the silver in the "poisoned" Ag_2S sites are sufficiently "ionic" so that they are in the $^+1$ state, and thus able to pi-complex with olefins.

5 While preferred embodiments of the invention have been described in detail, it will be apparent to those skilled in the art that the disclosed embodiments may be modified. Therefore, the foregoing description is to be considered exemplary rather than limiting, and the true scope of the invention is that defined in the
10 following claims.

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What is claimed is:

1 1. A method of separating gaseous alkene
2 selected from the group consisting of ethylene, propylene
3 and mixtures thereof, from a gaseous mixture including
4 the alkene and a sulfur compound, the method comprising
5 the steps of:

17 changing at least one of the pressure and
18 temperature to thereby release the alkene-rich component
19 from the adsorbent;

20 wherein the adsorbent substantially maintains
21 its adsorbent capacity and preference for the alkene in
22 the presence of the sulfur compound.

1 2. The method as defined in claim 1 wherein
2 the silver compound is silver nitrate (AgNO_3) and the
3 carrier is silica (SiO_2).

1 3. The method as defined in claim 1 wherein
2 the silver compound is a silver salt, and wherein the
3 salt is selected from the group consisting of acetate,
4 benzoate, bromate, chlorate, perchlorate, chlorite,
5 citrate, fluoride, nitrate, nitrite, sulfate, and
6 mixtures thereof.

1 4. The method as defined in claim 1 wherein
2 the carrier has a BET surface area greater than about 50

3 square meters per gram and up to about 2,000 square
4 meters per gram, and comprises a plurality of pores
5 having a pore size greater than about 3 angstroms and up
6 to about 10 microns.

1 5. The method as defined in claim 1 wherein
2 the carrier is a high surface area support selected from
3 the group consisting of refractory inorganic oxide,
4 molecular sieve, activated carbon, and mixtures thereof.

1 6. The method as defined in claim 5 wherein
2 the refractory inorganic oxide is selected from the group
3 consisting of pillared clay, alumina and silica.

1 7. The method as defined in claim 1 wherein
2 the silver compound is a silver (I) halide and the
3 carrier is silica.

1 8. The method as defined in claim 1 wherein
2 the selected pressure of preferential adsorption is a
3 first pressure, and the pressure of release is a second
4 pressure less than the first pressure, and wherein the
5 first pressure is in a range of about 1 atmosphere to
6 about 35 atmospheres, and further wherein the second
7 pressure is in a range of about 0.01 atm to about 5 atm.

1 9. The method as defined in claim 1 wherein
2 the selected temperature of preferential adsorption is a
3 first temperature, and the temperature of release is a
4 second temperature greater than the first temperature,
5 and wherein the first temperature is in a range of about
6 0°C to about 50°C, and further wherein the second
7 temperature is in a range of about 70°C to about 200°C.

1 10. The method as defined in claim 1 wherein
2 the retaining of the alkene is accomplished by formation

3 of π -complexation bonds between the silver compound and
4 the alkene.

1 11. A sulfur tolerant adsorbent for
2 preferential adsorption of gaseous alkene from a gaseous
3 mixture including the alkene and a sulfur compound, the
4 adsorbent comprising:

5 a carrier; and

6 a silver compound supported on the carrier,
7 wherein the silver compound is a silver salt, and wherein
8 the salt is selected from the group consisting of
9 acetate, benzoate, bromate, chlorate, perchlorate,
10 chlorite, citrate, fluoride, nitrate, nitrite, and
11 sulfate;

12 wherein the carrier has a BET surface area
13 greater than about 50 square meters per gram and up to
14 about 2,000 square meters per gram and comprising a
15 plurality of pores having a pore size greater than about
16 3 angstroms and up to about 10 microns;

17 and wherein the adsorbent substantially
18 maintains its adsorbent capacity and preference for the
19 alkene in the presence of the sulfur compound.

20 12. The adsorbent as defined in claim 11
21 wherein the adsorbent comprises finely divided particles
22 of silica (SiO_2) with silver nitrate (AgNO_3) dispersed on
23 and supported on the particles.

1 13. The adsorbent as defined in claim 11
2 wherein the carrier is selected from the group consisting
3 of refractory inorganic oxide, molecular sieve, and
4 activated carbon in particle form.

1 14. The adsorbent as defined in claim 13
2 wherein the refractory oxide is selected from the group
3 consisting of pillared clay, alumina and silica.

1 20. The method as defined in claim 15 wherein
2 the mixture comprises at least one mono-olefin having as
3 many carbon atoms as the diene, wherein the diene is
4 selected from the group consisting of butadiene,
5 hexadiene, octadiene, and mixtures thereof; and wherein
6 the mono-olefin is selected from the group consisting of
7 butene, hexene, octene, and mixtures thereof.

1 21. The method as defined in claim 20 wherein
2 the mono-olefin is butene and the diene is butadiene.

1 22. The method as defined in claim 20 wherein
2 the mixture comprises the mono-olefin in a gaseous state
3 and saturated with the diene.

1 23. The method as defined in claim 15 wherein
2 essentially all cationic sites of the ion-exchanged
3 zeolite contain the silver cation.

1 24. The method as defined in claim 16 wherein
2 the selected pressure of preferential adsorption is a
3 first pressure, and the pressure of release is a second
4 pressure less than the first pressure, wherein the first
5 pressure is in a range of about 1 atmosphere to about 35
6 atmospheres, and wherein the second pressure is in a
7 range of about 0.01 atmosphere to about 5 atmospheres.

1 25. The method as defined in claim 16 wherein
2 the selected temperature of preferential adsorption is a
3 first temperature, and the temperature of release is a
4 second temperature greater than the first temperature,
5 wherein the first temperature is in a range of about 0°C
6 to about 150°C, and wherein the second temperature is in
7 a range of about 70°C to about 250°C.

1 26. A method for separating a diene from a
2 mixture including the diene and a sulfur compound, the
3 process comprising the steps of:

4 contacting the mixture with an adsorbent which
5 preferentially adsorbs the diene at a first temperature,
6 thereby producing a non-adsorbed component and a diene-
7 rich adsorbed component, wherein the adsorbent comprises
8 zeolite A having exchangeable cationic sites, a plurality
9 of the zeolite A sites having an alkali metal cation or
10 an alkaline earth metal cation present; and

11 releasing the diene-rich adsorbed component
12 from the adsorbent by elevating the temperature to a
13 second temperature which ranges between about 70°C and
14 about 120°C;

15 wherein the adsorbent substantially maintains
16 its adsorbent capacity and preference for the diene in
17 the presence of the sulfur compound.

1 27. The method as defined in claim 26 wherein
2 the diene is selected from the group consisting of
3 butadiene, hexadiene, octadiene, and mixtures thereof.

1 28. The process as defined in claim 27 wherein
2 a selected pressure of preferential adsorption is a first
3 pressure, and a pressure of release is a second pressure
4 less than the first pressure, wherein the first pressure
5 is in a range of about 1 atmosphere to about 35
6 atmospheres, and wherein the second pressure is in a
7 range of about 0.01 atmosphere to about 5 atmospheres.

1 29. The method as defined in claim 1 wherein
2 the sulfur compound is hydrogen sulfide, and wherein the
3 hydrogen sulfide is present in amounts up to about 66
4 mole%.

1 30. The method as defined in claim 11 wherein
2 the sulfur compound is hydrogen sulfide, and wherein the

3 hydrogen sulfide is present in amounts up to about 66
4 mole%.

1 31. The method as defined in claim 15 wherein
2 the sulfur compound is hydrogen sulfide, and wherein the
3 hydrogen sulfide is present in amounts up to about 66
4 mole%.

1 32. The method as defined in claim 26 wherein
2 the sulfur compound is hydrogen sulfide, and wherein the
3 hydrogen sulfide is present in amounts up to about 66
4 mole%.

SULFUR RESISTANT ADSORBENTS**ABSTRACT OF THE DISCLOSURE**

Sulfur resistant/tolerant adsorbents useful for separating olefins from paraffins in a cracked gas stream including hydrogen sulfide. The method comprises the steps of contacting the gaseous mixture with an adsorbent which preferentially adsorbs the alkene, at a selected temperature and pressure, thereby producing a non-adsorbed component and an alkene-rich adsorbed component; the adsorbent comprising a carrier having a surface area, the carrier having been impregnated with a silver compound by incipient wetness, the silver compound releasably retaining the alkene; and changing at least one of the pressure and temperature to thereby release the alkene-rich component from the adsorbent. The adsorbent substantially maintains its adsorbent capacity and preference for the alkene in the presence of the sulfur compound. Sulfur resistant/tolerant adsorbents useful for selectively separating dienes from a mixture, particularly one containing mono-olefins and hydrogen sulfide, are also disclosed.

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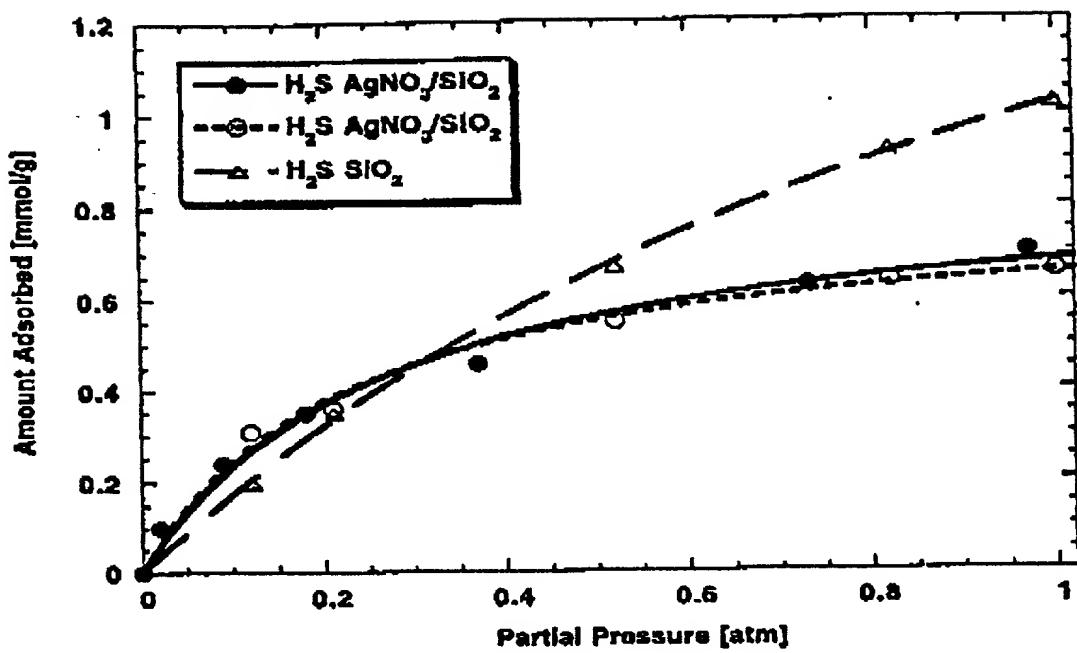


Figure 1 Comparison of H_2S adsorption on SiO_2 and $\text{AgNO}_3/\text{SiO}_2$ at 70°C

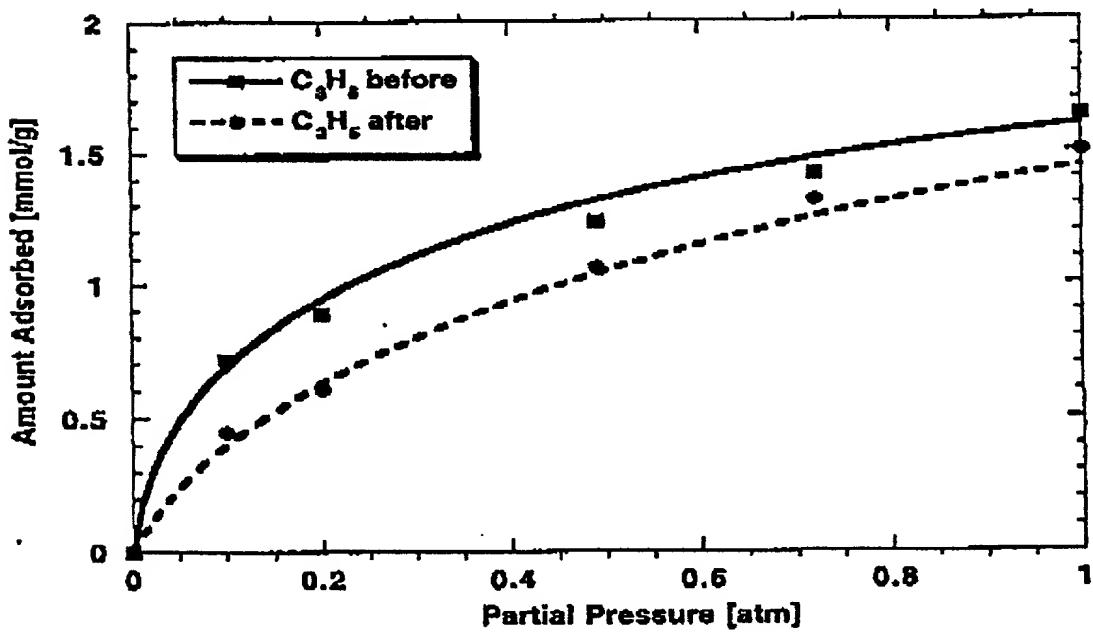


Figure 2 H_2S effect on olefin adsorption on $\text{AgNO}_3/\text{SiO}_2$.

Fig 3

C_2H_4 Cyclic Adsorption on $AgNO_3/SiO_2$

Isotherm @ 50 °C; $P = 1$ atm

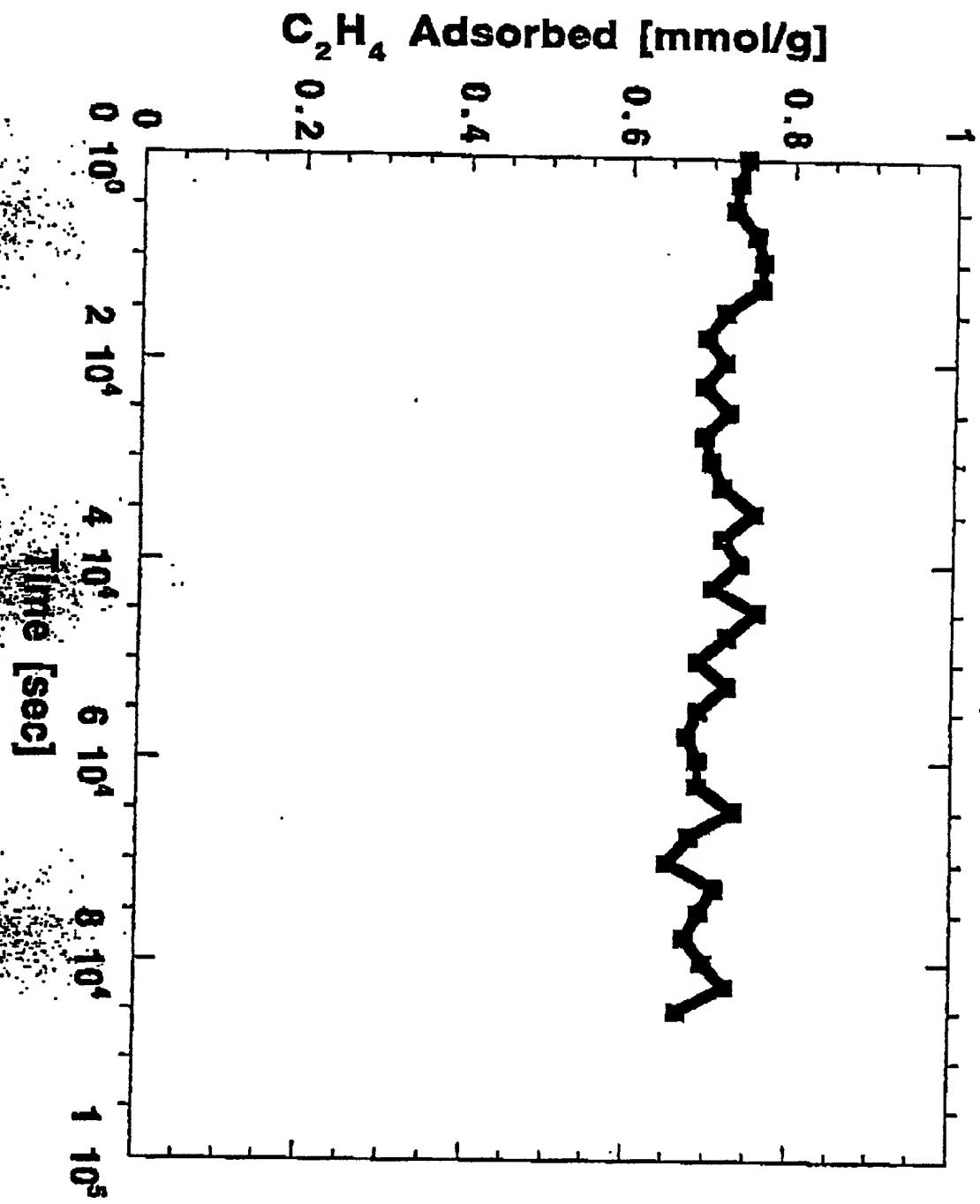
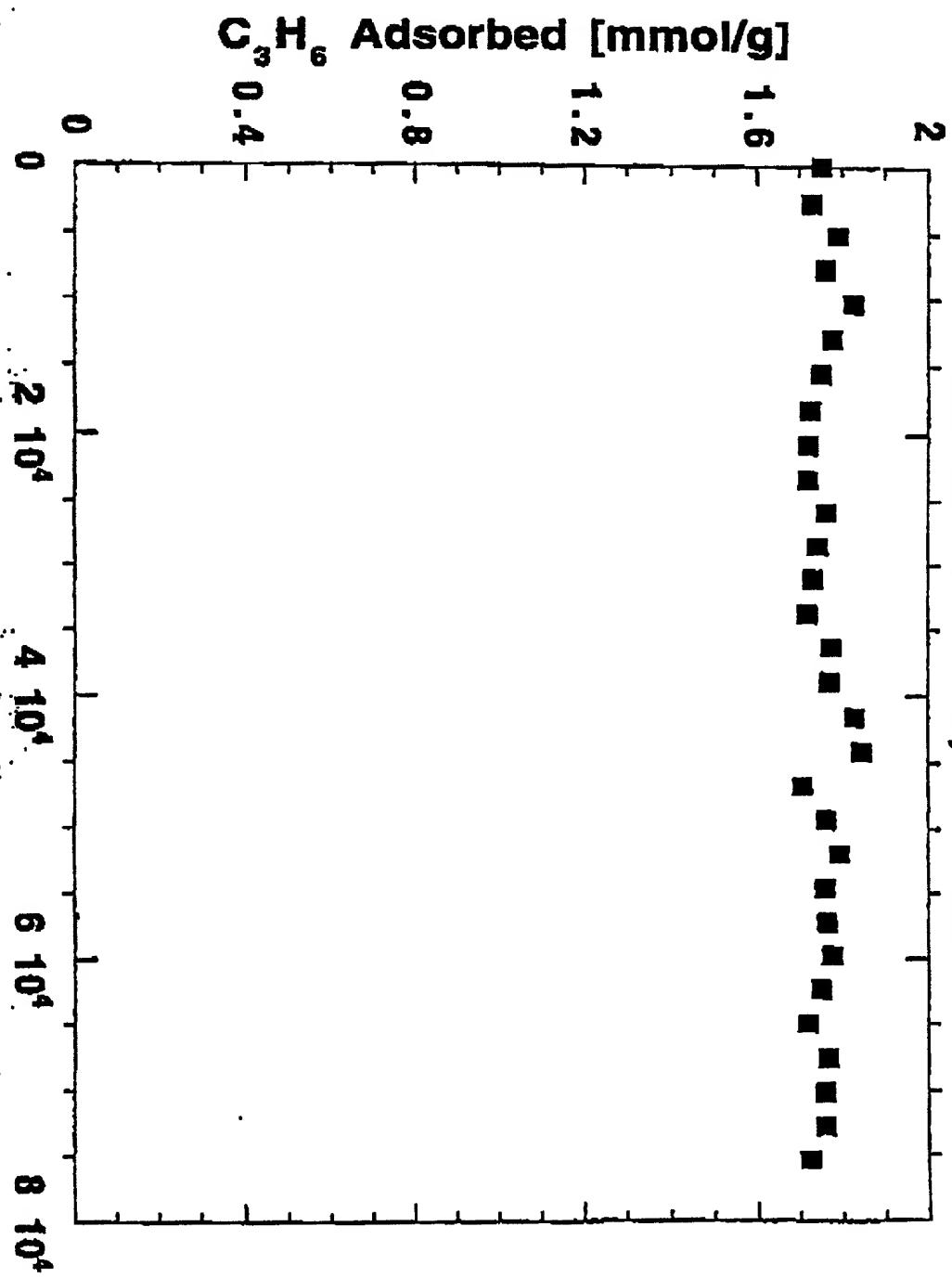


Fig 4

C_3H_6 Cyclic Adsorption on $AgNO_3/SiO_2$

Isotherm @ 50 °C; $P = 1$ atm



C_3H_6 Cyclic Adsorption on $AgNO_3/SiO_2$

Isotherm @ 120 °C; $P = 1$ atm

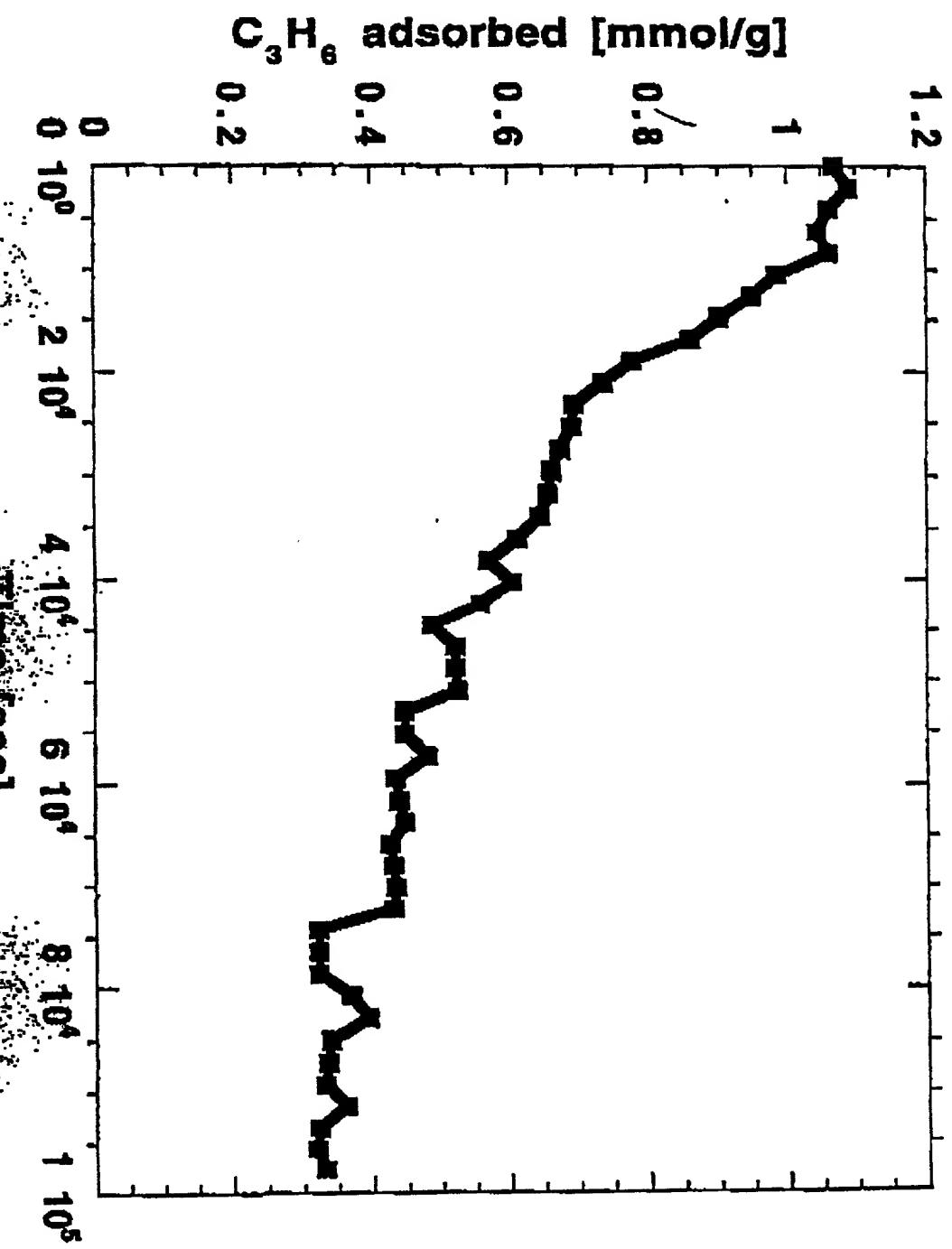


Figure 5

H_2S Adsorption and Desorption on SiO_2 (298K)

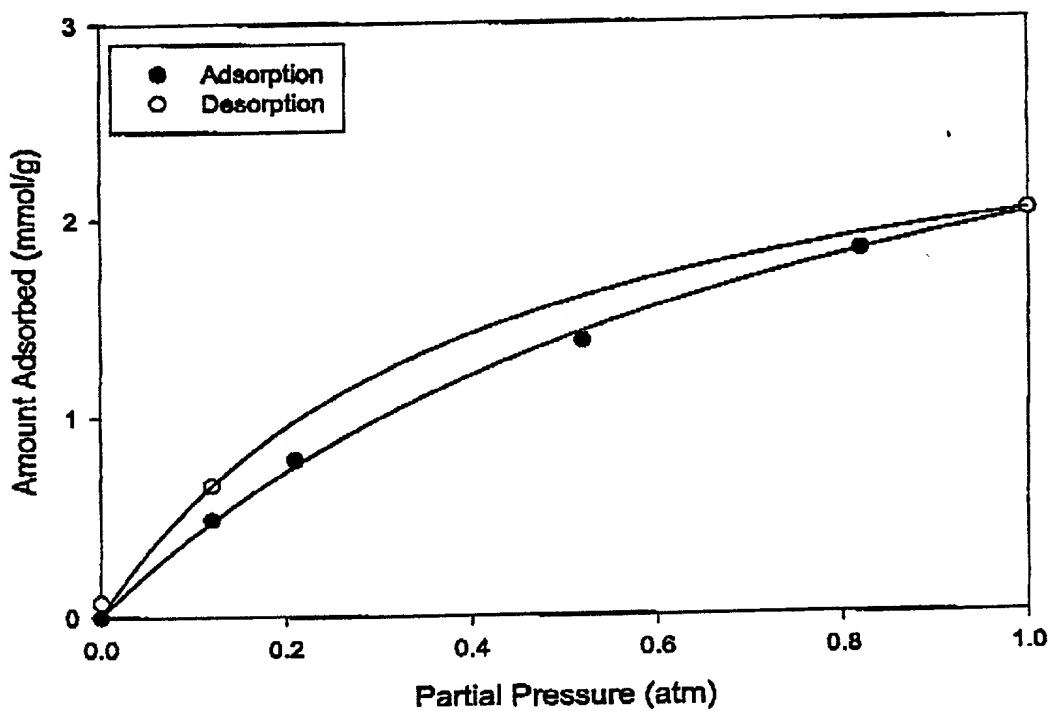
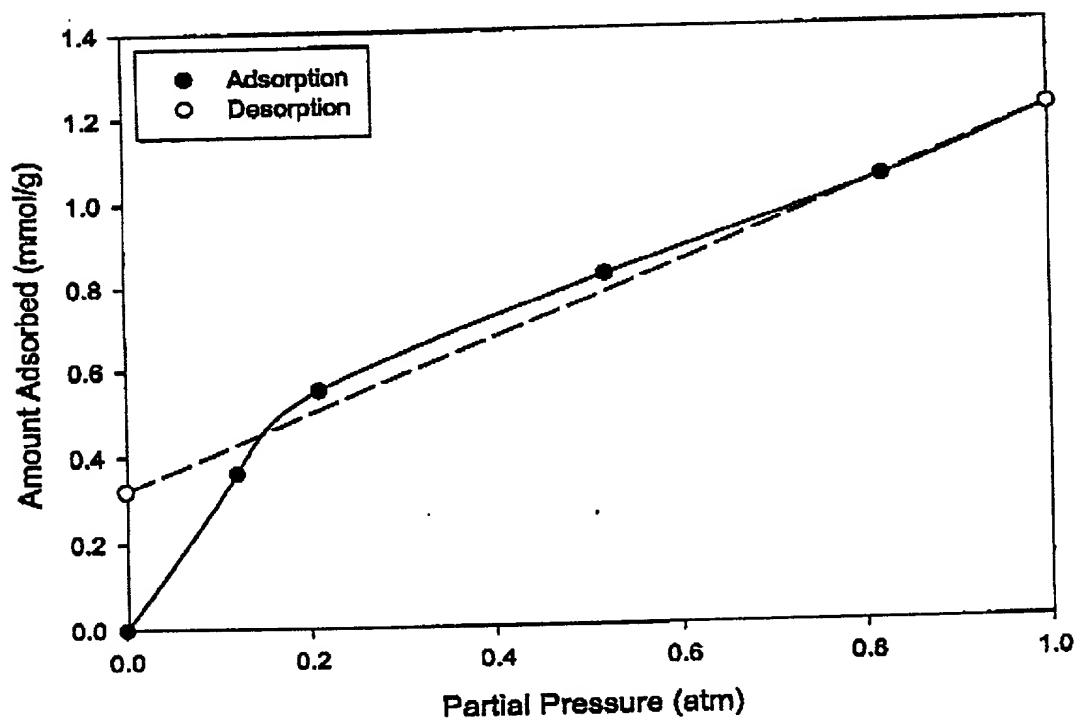


Fig 6

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H_2S Adsorption and Desorption on $\text{AgNO}_3/\text{SiO}_2$ (298K)



Fig

H_2S Adsorption and Desorption on $\text{AgNO}_3/\text{SiO}_2$ (343K)

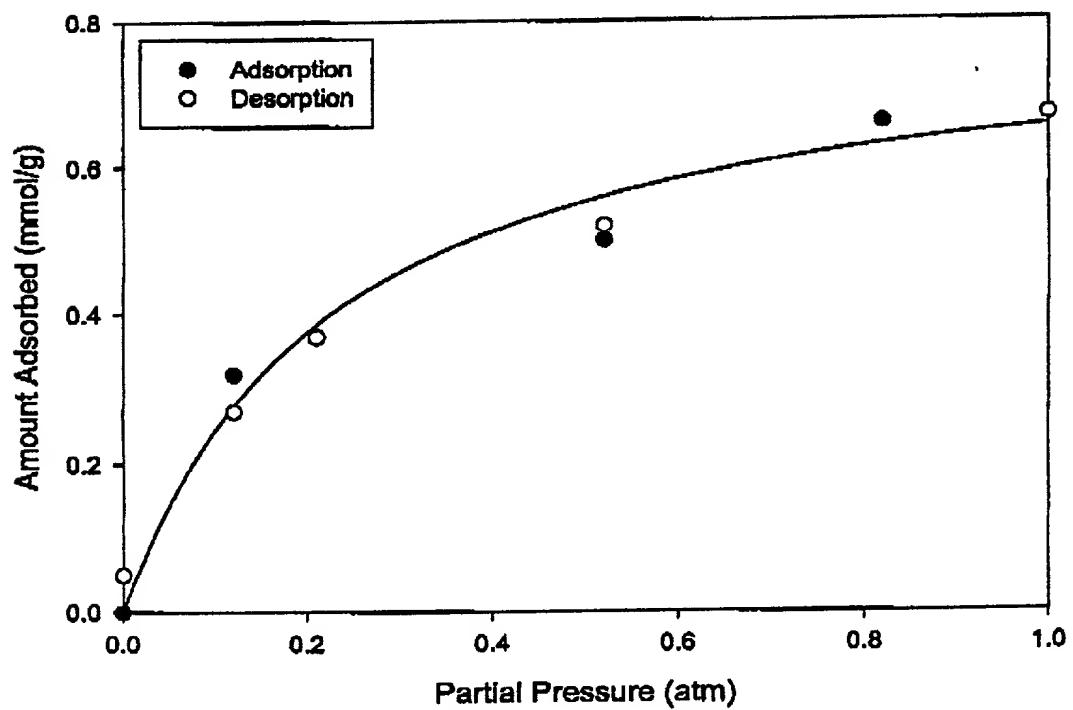


Fig 2

Effect of H_2S Poisoning on $\text{AgNO}_3/\text{SiO}_2$
Capacity for C_3H_6 (343K)

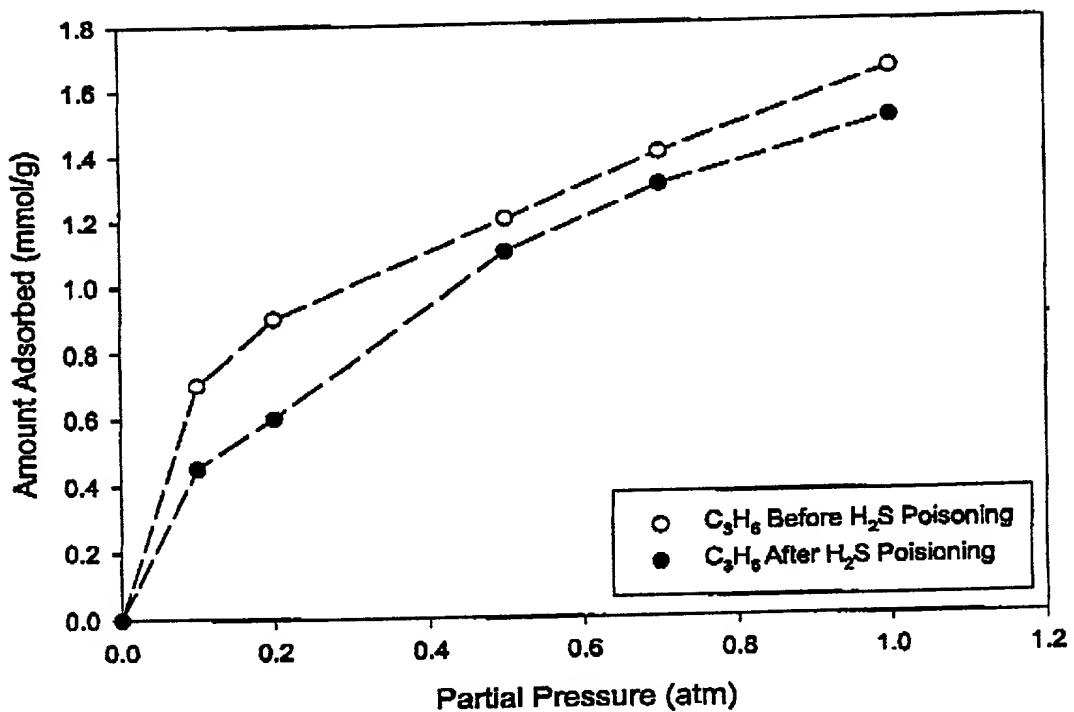
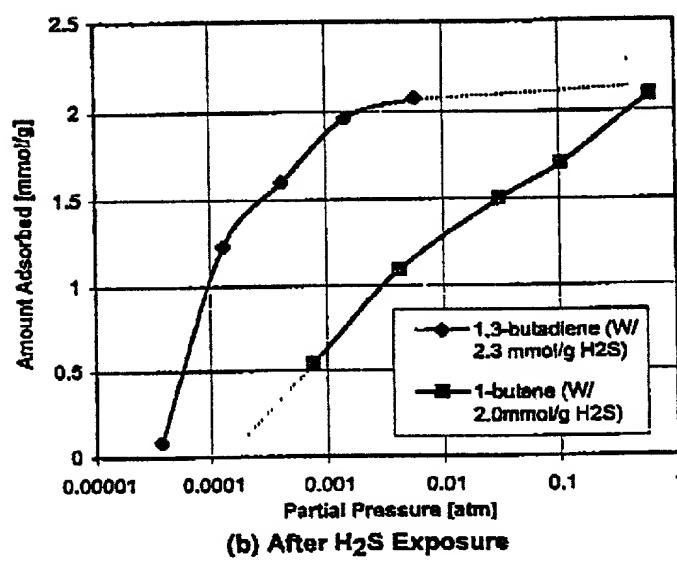
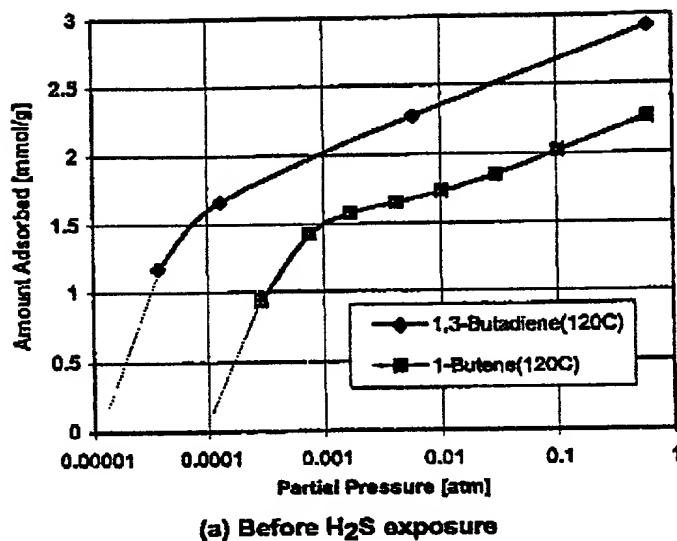


Figure 9



Isotherms of 1,3-butadiene and 1-butene at 120 °C.

Fig 10

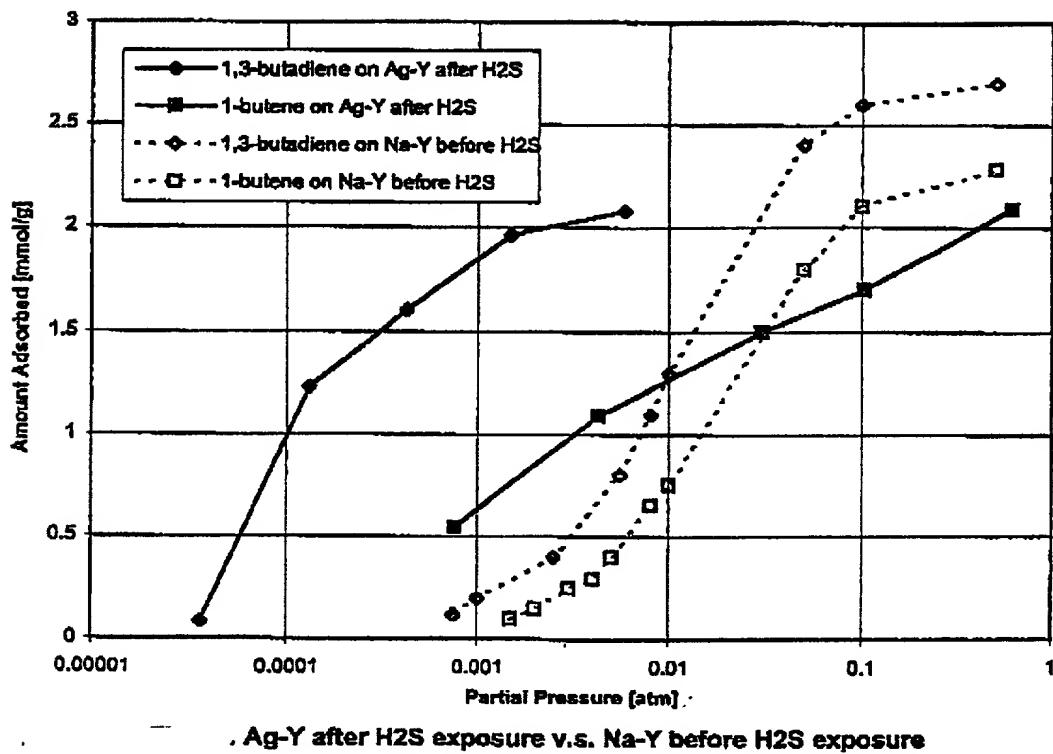
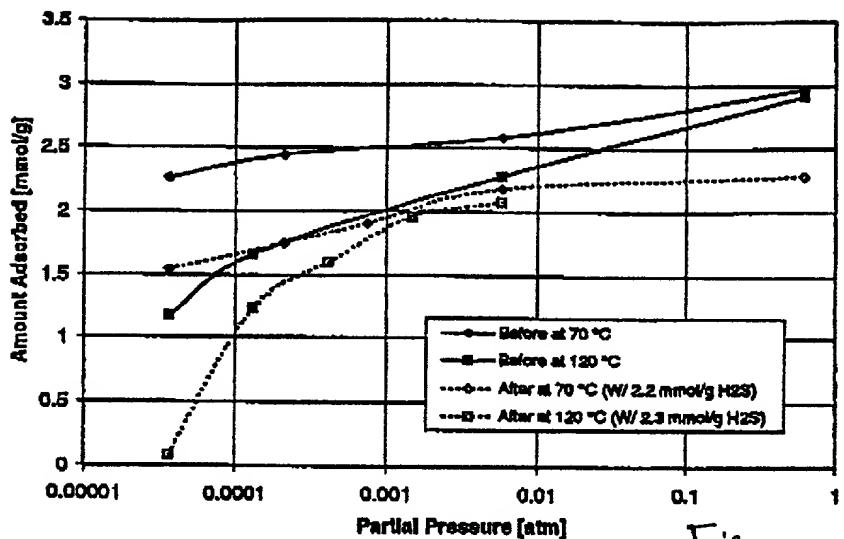
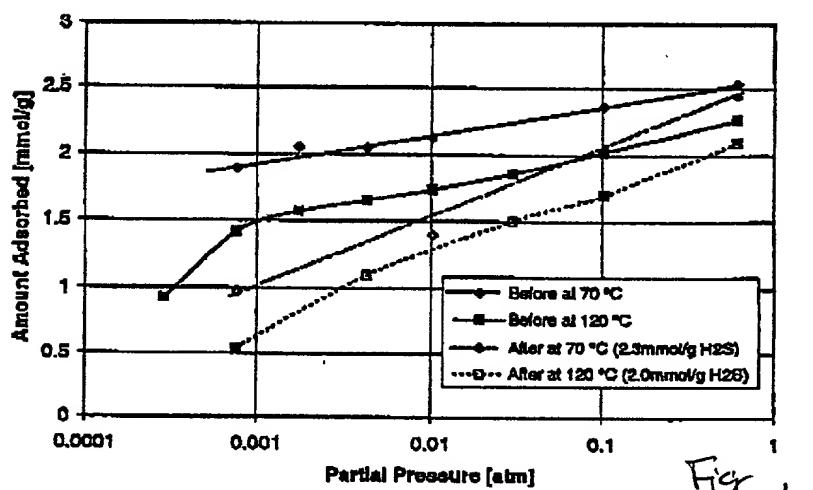


Fig. 11



1. Isotherms of 1,3-butadiene before and after H₂S Exposure

Fig 12a



2. Isotherms of 1-butene before and after H₂S exposure

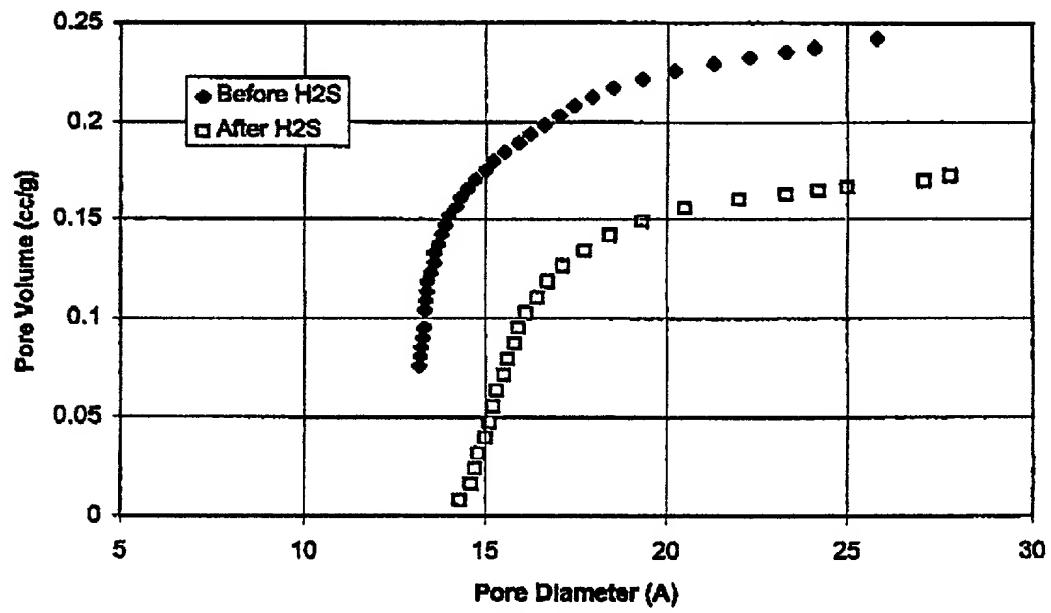
Fig 12b

Table. Calculated Heat of Adsorption

	1,3-butadiene	1-butene
Before H ₂ S Exposure	24-29 kcal/mol	16-22 kcal/mol
After H ₂ S Exposure	7-11 kcal/mol	6-7 kcal/mol

Fig 12c

Fig 12



Cumulative pore volume of Ag-Y before and after H₂S exposure.

Fig 13

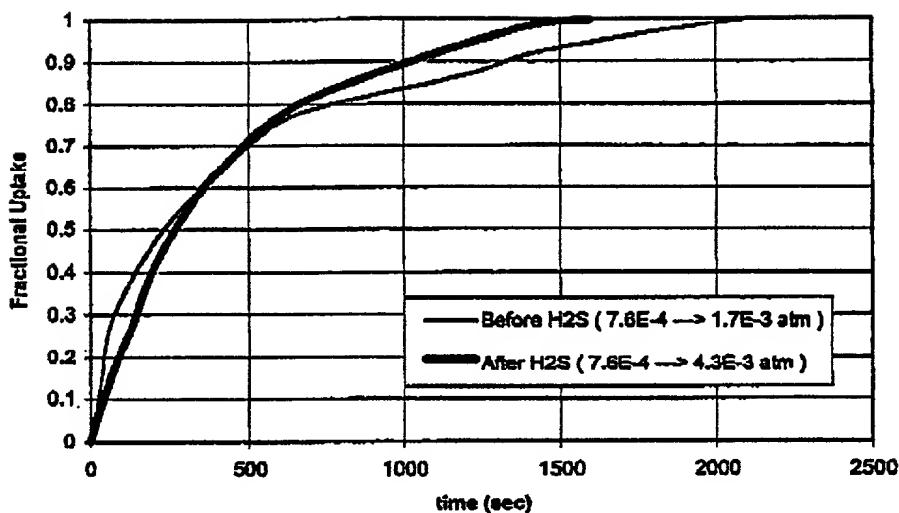


Fig 14 (a) 1-butene at 120 °C

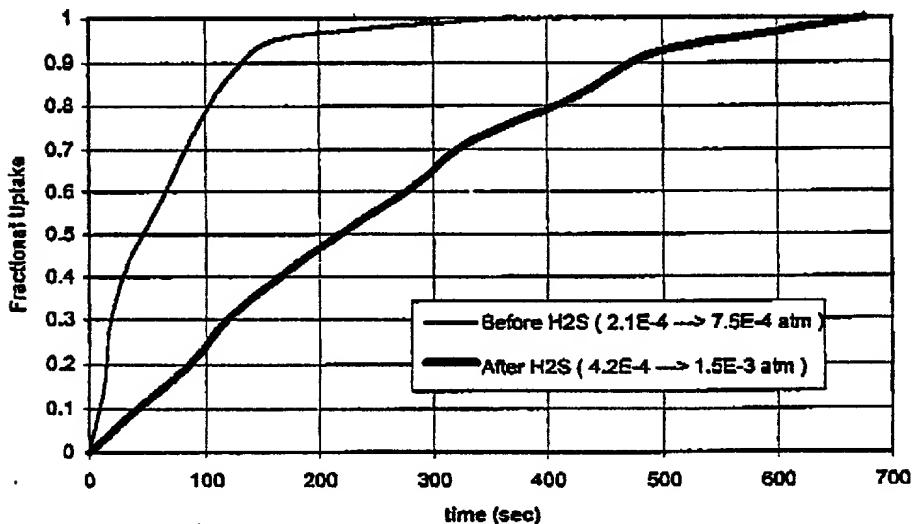


Fig 14 (b) 1,3-butadiene at 120 °C

Fractional uptake curves of 1-butene and 1,3-butadiene before and after H₂S exposure.

Table. Diffusion time constants (1/s)

	Before H ₂ S exposure	After H ₂ S exposure
1-butene	1.8×10^{-4} ($7.6 \times 10^{-4} \rightarrow 1.7 \times 10^{-3}$ atm)	1.5×10^{-4} ($7.6 \times 10^{-4} \rightarrow 4.3 \times 10^{-3}$ atm)
1,3-butadiene	8.7×10^{-4} ($2.1 \times 10^{-4} \rightarrow 7.5 \times 10^{-4}$ atm)	2.6×10^{-4} ($4.2 \times 10^{-4} \rightarrow 1.5 \times 10^{-3}$ atm)

Fig 14 C

Fig 14

2) Sorbent for purification of 1-Hexene by removal of Benzene.

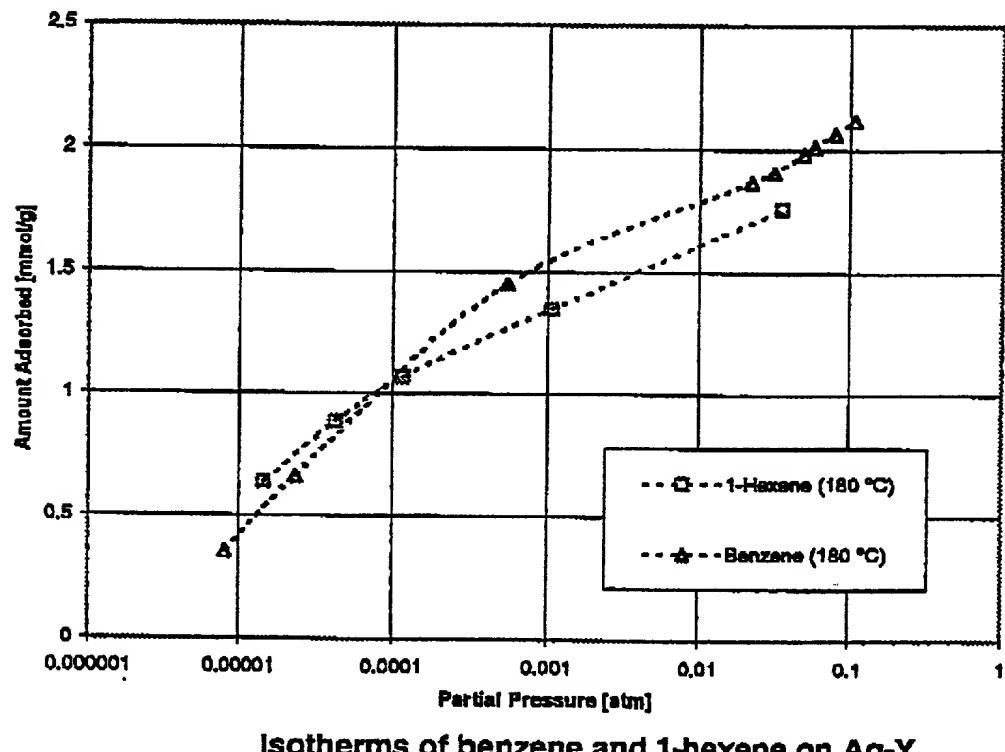


Fig 15

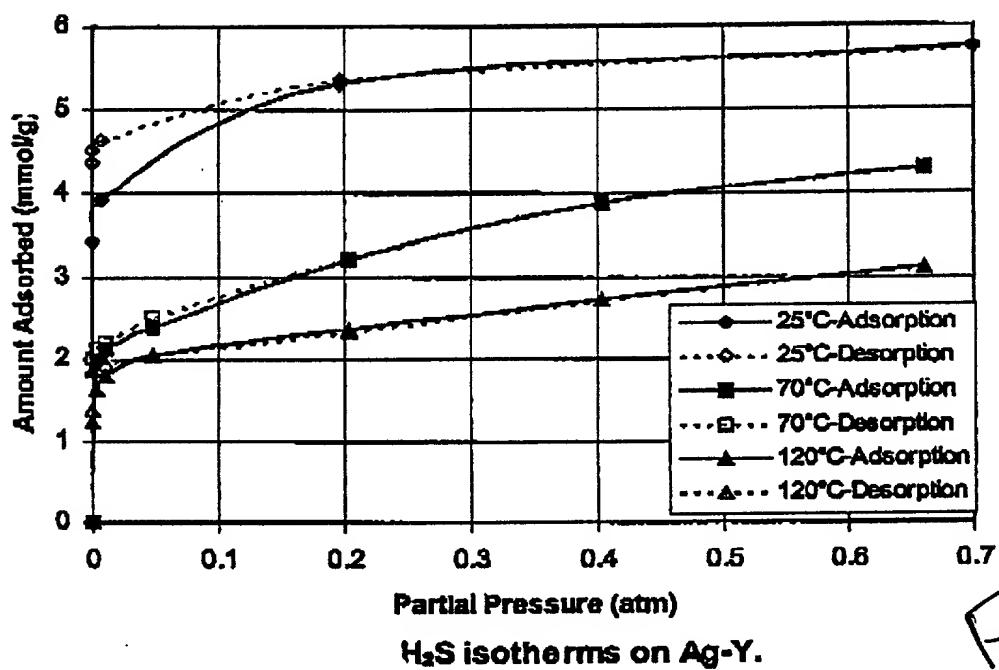


Fig 16

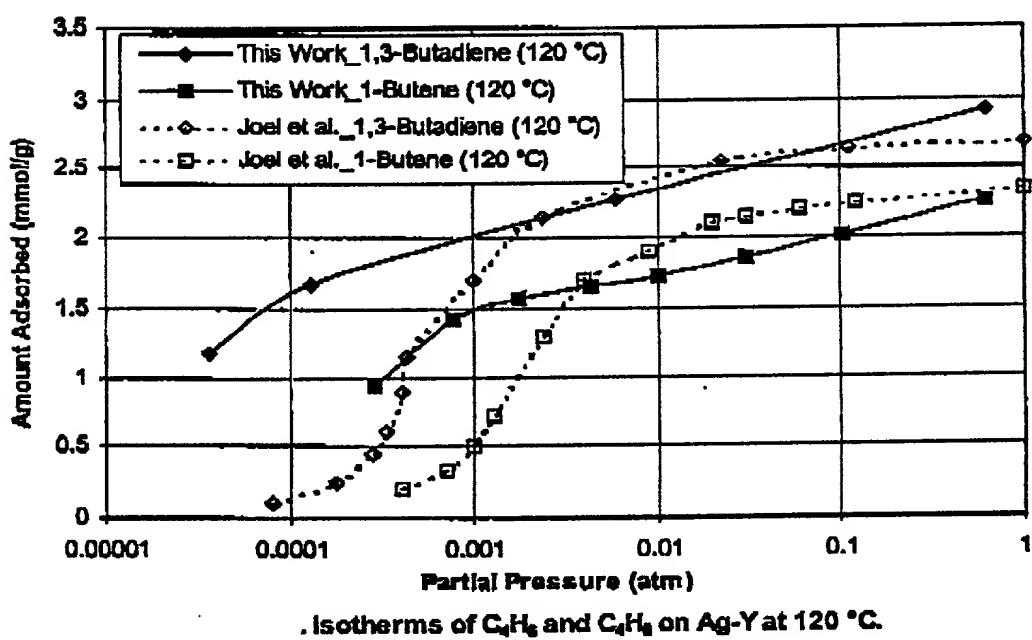


Fig 17

FIG - 18

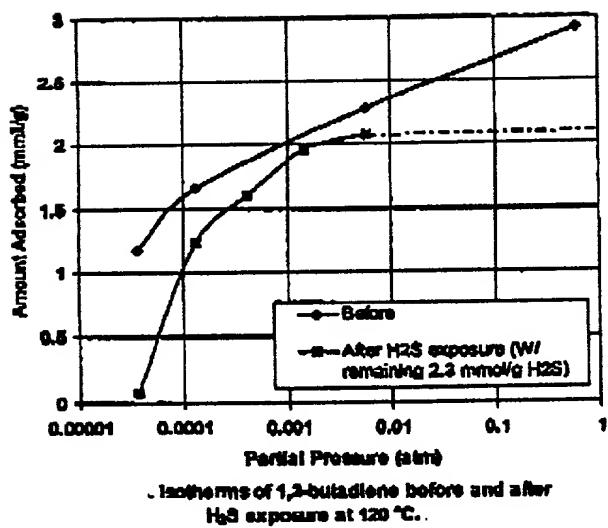


FIG - 19

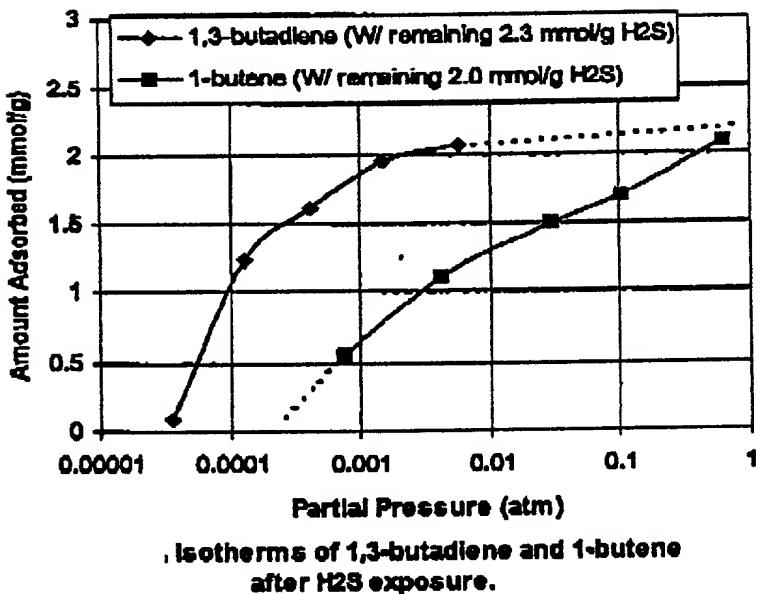
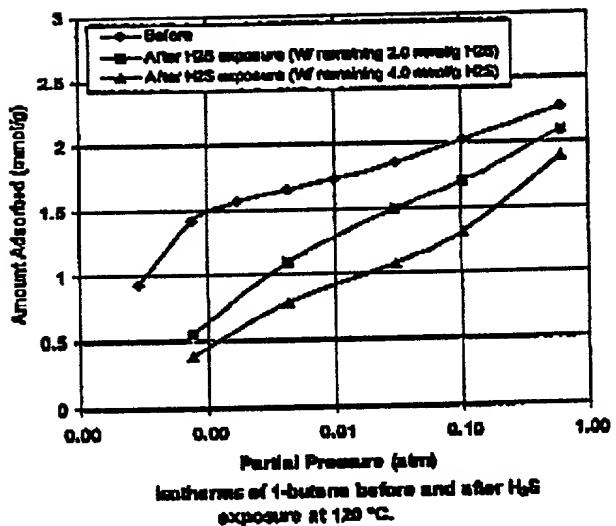


Fig 20

Our Reference: UMMG-1544-C

COMBINED DECLARATION AND POWER OF ATTORNEY
DECLARATION:

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

SULFUR RESISTANT ADSORBENTS

the specification of which (check only one item below):

is attached hereto

was filed as United States application Serial No. _____ on _____, and was amended on or through _____ (if applicable).

was filed as PCT international application Number _____ on _____, and was amended under PCT Article 19 on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate or 365(a) of any PCT international application(s) which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT international application(s) having a filing date before that of the application on which priority is claimed:

Prior Foreign/PCT Application(s) and any Priority Claims Under 35 U.S.C. 119:

Priority Claimed

(Number)	(Country)	(Day/Mo/Yr Filed)	<input type="checkbox"/>	<input checked="" type="checkbox"/>
			<input type="checkbox"/>	<input checked="" type="checkbox"/>

I hereby claim the benefit under 35 U.S.C. 119(c) of any United States provisional application(s) listed below.

(Application Number)	(Filing Date)

I hereby claim the benefit under Title 35, United States Code, 120 of any United States application(s) or 365(c) of any PCT international application(s) designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT international application(s) in the manner provided by the first paragraph of Title 35, United States Code, 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

Prior U. S. Application(s) or PCT International Application(s) Designating the U.S. for Benefit Under 35 U.S.C. 120:

(Application Number)	(Filing Date)	(Status: patented, pending, abandoned)

(Application Number)

(Filing Date)

(Status: patented, pending, abandoned)

POWER OF ATTORNEY:

I hereby appoint the following attorneys Linda M. Deschere, Patent Office Registration No. 34811, and Julia Church Dierker, Patent Office Registration No. 33368, as my attorneys, to prosecute this application and to transact all business in the United States Patent and Trademark Office connected therewith.

Send all correspondence to: **Linda M. Deschere**
Young & Basilic, P.C.
3001 West Big Beaver Road, Suite 624
Troy, Michigan 48084
Phone: (248) 649-3333

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18U of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of sole or first inventor **Curtis L. Munson**

Inventor's Signature John J. Hansen

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Full name of second joint inventor, if any **Ralph T. Yang**

Inventor's Signature See separate document

Date _____ Citizenship United States

Residence 2627 Pin Oak Drive, Ann Arbor, Michigan 48103

Post Office Address (Same as above)

[] Additional inventors are being named on separately numbered sheets attached hereto.

Our Reference: UMMQ-1544-C

COMBINED DECLARATION AND POWER OF ATTORNEY**DECLARATION:**

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

SULFUR RESISTANT ADSORBENTS

the specification of which (check only one item below):

 is attached hereto. was filed as United States application Serial No. _____ on _____, and was amended on or through _____ (if applicable). was filed as PCT international application Number _____ on _____, and was amended under PCT Article 19 on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, 1.56.I hereby claim foreign priority benefits under Title 35, United States Code, 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate or 365(a) of any PCT international application(s) which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT international application(s) having a filing date before that of the application on which priority is claimed:Prior Foreign/PCT Application(s) and any Priority Claims Under 35 U.S.C. 119:

Priority Claimed

(Number)	(Country)	(Day/Mo/Yr Filed)	<input type="checkbox"/>	<input checked="" type="checkbox"/>
(Number)	(Country)	(Day/Mo/Yr Filed)	<input type="checkbox"/>	<input checked="" type="checkbox"/>

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(Application Number)	(Filing Date)
(Application Number)	(Filing Date)

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Prior U. S. Application(s) or PCT International Application(s) Designating the U.S. for Benefit Under 35 U.S.C. 120:

(Application Number)	(Filing Date)	(Status: patented, pending, abandoned)
(Application Number)	(Filing Date)	(Status: patented, pending, abandoned)

POWER OF ATTORNEY:

I hereby appoint the following attorneys Linda M. Deschere, Patent Office Registration No. 34811, and Julia Church Dierker, Patent Office Registration No. 33368, as my attorneys, to prosecute this application and to transact all business in the United States Patent and Trademark Office connected therewith.

Send all correspondence to: Linda M. Deschere

Young & Basile, P.C.
3001 West Big Beaver Road, Suite 624
Troy, Michigan 48084
Phone: (248) 649-3333

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of sole or first inventor Curtis L. Munson

Inventor's Signature See separate document

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Full name of second joint inventor, if any Ralph T. Yang

Inventor's Signature Ralph T. Yang

Date 8/7/00 Citizenship United States

Residence 2627 Pin Oak Drive, Ann Arbor, Michigan 48103

Post Office Address (Same as above)

Additional inventors are being named on separately numbered sheets attached hereto.